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A Comparative Simulation Study on the Acoustical Condition of Malaysian Public Secondary Schools' Classrooms

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ABSTRACT

The establishment of classroom design guidelines is essential in order to provide a conducive setting that promotes optimal teaching and learning outcomes. Most of the learning methods involve hearing and listening which require students to use their auditory skills for speech comprehension. It is vital to design a classroom with optimal acoustic conditions for good speech intelligibility and proper listening quality. However, the importance of classroom acoustics in designing a comfortable learning environment is often neglected. Therefore, this study seeks to i) investigate the acoustic conditions of the existing public-school classrooms and ii) evaluate the effect of several treatment alternatives on acoustic performance through the simulation method. Three (3) classrooms from different public secondary schools were chosen for acoustic evaluations. The existing classrooms' acoustic parameters, namely reverberation time (RT) and speech transmission index (STI), were initially identified. The impact of acoustic treatments on acoustic performance was further assessed, encompassing variations in ceiling profile configurations and adjustments to surface materials. The findings indicate that the current classrooms' reverberation time (RT) and speech transmission index (STI) did not meet the standard recommendations. Despite the prevailing circumstances, the implementation of acoustic treatments on the ceiling profile and alterations to the surface material yield substantial enhancements in acoustic performance, ultimately leading to the attainment of the required optimal acoustic environment inside the classroom setting.

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INTRODUCTION

Creating an environment that is conducive to learning is crucial in order to promote effective teaching and learning processes. A range of environmental factors exert an effect on the creation of a suitable learning environment. The acoustic environment within the classroom has a significant role in shaping the instructional and learning outcomes for both teachers and students. The primary locus for formal education is the classroom, wherein the pedagogical process entails rigorous verbal exchange between educators and learners, as well as among peers [1]. Research findings suggest that students devote a considerable proportion of their time inside educational settings, often ranging from 45% to 75%, to the cognitive task of understanding and processing the speech delivered by their teachers and peers [2][3]. The presence of poor acoustics in a classroom requires the students to exert heightened levels of focus, resulting in a decline in academic performance [4][5]. Conversely, the acoustic qualities of the classroom had a significant influence on the teacher's well-being. In a classroom setting with a high reverberation time and unacceptable background noise, teachers involuntarily raise their voices in order to effectively communicate with the students [6][7]. This occurrence is known as the Lombard Effect.

Speech intelligibility is the primary focus in designing favourable acoustic conditions in classrooms to ensure the speech delivered is comprehensible to the listeners. The prediction of the speech intelligibility of the listeners in a classroom can be quantified by using the Speech Transmission Index (STI). The STI value varied from "0" to "1" and is represented by the quality rating scale from "bad", "poor", "fair", "good", and "excellent". The speech intelligibility quality is affected by several room acoustic parameters namely reverberation time [8] signal-to-noise ratio [9] , background noise [7], and architectural design of the classroom [10]. Consequently, a range of classroom acoustic regulations have been implemented to address the issue of acoustic considerations.

The two most established classroom acoustic regulations are Building Bulletin 93 [11] published by the United Kingdom (UK) and ANSI/ASA12.60 2010 [12] in the United States of America (USA). Both regulations focus on the maximum permissible value of background noise and reverberation time for learning spaces according to different categories. Based on the regulation outlined by Building Bulletin 93 [11], it is advised that the reverberation time (RT) within primary school should be below 0.6 and 0.8 s for newly constructed and refurbished classrooms, and in secondary school classrooms, it should be below 0.8 and 1 s for newly constructed and refurbished classrooms. The allowed maximum level of background noise in an unoccupied classroom, as outlined in acoustic regulation, is set at 35 dBA.

Whereas, the ANSI/ASA S12/60 2010 [12] stated that classrooms with volumes below 283 m^3 should adhere to a maximum reverberation time (RT) of 0.6 s. Similarly, classrooms with volumes ranging from 283 m^3 to 566 m^3 should maintain a maximum RT of 0.7 s. The same maximum background noise value of 35 dBA was regulated in the ANSI/ASA S12.60 2002 guideline.

Over the course of several decades, spanning from its establishment to the current day, the architectural design and the construction method employed in public schools in Malaysia have exhibited a consistent lack of change [13]. Based on empirical observations, it is evident that public school design in Malaysia may be classified into two separate categories, namely one-off design and standard design. The phrase "one-off design" refers to a design that has a unique layout and architectural facade, setting it apart from other structures. The term "standard design" pertains to a specific type of school design that encompasses repetitive external aesthetics, spatial organisation, layout, and choice of building materials. Nordin et al. [14] have classified public school design into three separate periods: the post-independence era until the 1970s, the era encompassing the 1980s and 1990s, and the post-millennium period. Although there were minimal differences in the design of the facades among these three groups, similarities were seen in other elements such as the form and layout of the rooms, the materials used, the size and capacity of the spaces, and the presence of specific services. Based on the design criteria established by the Ministry of Education (MOE) as stated by the Jawatankuasa Standard dan Kos [15], it is apparent that public schools in Malaysia utilise a combination of natural ventilation, mechanical ventilation, and natural lighting as means of illumination. This is consistent with the theoretical passive design concept, which seeks to achieve energy efficiency in buildings while still prioritising user comfort. Nevertheless, this would give rise to another concern pertaining to the acoustic preferences in educational settings.

Therefore, this study seeks to evaluate the acoustical performance of selected public secondary school classrooms in Malaysia by using computer simulation, ODEON Room Acoustic Software. The influence of i) ceiling profile configurations and ii) surface material treatments on reverberation time (RT) and speech transmission Index (STI) was thoroughly analysed.

RESEARCH METHODOLOGY

Classroom Description

Three (3) classrooms from public secondary schools that were established in distinct periods namely pre-independence era, post-independence era and millennial era were chosen for this study. School A is classified as an all-boys public secondary school, situated in the northern region of Kuala Lumpur City, Malaysia. Schools B and C are both coeducational secondary schools located in the Petaling District of Selangor, Malaysia. The chosen school buildings exhibit varying construction methods, encompassing both traditional on-site construction and industrialised building systems (IBS). A comparative analysis was conducted on the architectural design of classrooms, encompassing elements such as layout, surface materials, floor area, and volume. The classrooms' detailed descriptions are tabulated in Table 1. Drawings was obtained from the relevant schools or from Built Environment Faculty Measured Drawing archives.

Table 1: School classroom descriptions

School	Establishment year	Length (m)	Width (m)	Height (m)	Floor Area (m^2)	Volume (m^3)	Capacity (no)
A	1917	7.65	7.56	5.45	58.5	318.8	28
B	1971	8.85	9.30	3.15	82.3	259.2	30
C	2012	9.00	7.50	3.05	67.5	205.9	33

Table 2: Sound source and receiver coordinates for each school's classroom

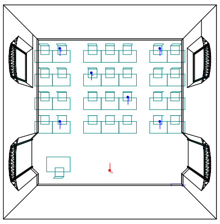
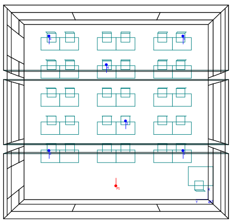
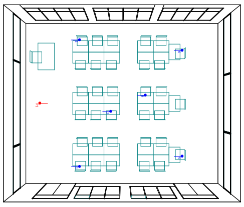
Classroom's Layout	Sound source and receivers' coordinates			
School A	**Item**	**x**	**y**	**z**
	Sound source	1.00	3.83	1.50
	Receiver 1	3.35	1.35	1.20
	Receiver 2	3.35	6.30	1.20
	Receiver 3	4.55	2.93	1.20
	Receiver 4	5.75	4.73	1.20
	Receiver 5	6.95	1.35	1.20
	Receiver 6	6.95	6.30	1.20
School B	**Item**	**x**	**y**	**z**
	Sound source	1.00	4.65	1.50
	Receiver 1	2.60	1.50	1.20
	Receiver 2	2.60	7.80	1.20
	Receiver 3	4.00	4.20	1.20
	Receiver 4	6.65	5.10	1.20
	Receiver 5	8.00	1.50	1.20
	Receiver 6	8.00	7.80	1.20
School C	**Item**	**x**	**y**	**z**
	Sound source	1.00	3.75	1.50
	Receiver 1	2.65	1.00	1.20
	Receiver 2	2.65	1.00	1.20
	Receiver 3	4.00	3.40	1.20
	Receiver 4	5.50	4.10	1.20
	Receiver 5	7.10	1.45	1.20
	Receiver 6	7.10	6.05	1.20

Table 3: Details of surface materials utilised for simulation

Component	**ODEON material library**	**Absorption coefficient (α) / Hz**			
		250	**500**	**1000**	**2000**
Floor	Smooth concrete, painted or glazed	0.01	0.01	0.02	0.02
Wall	Smooth brickwork with flush pointing, painted	0.01	0.02	0.02	0.02
Ceiling	Perforated 27mm gypsum board (16%), d=4.5mm 300mm from ceiling	0.55	0.60	0.90	0.86
Window	Glass, ordinary window glass	0.25	0.18	0.11	0.07
Door	Solid wooden door	0.10	0.06	0.08	0.10
Plastic chair	Adults in plastic and metal chairs in m^2 units	0.35	0.40	0.40	0.43
Wooden chair	Audience on wooden chairs, 1 per sq. m	0.24	0.56	0.69	0.81
Desk	Empty desk	0.13	0.14	0.17	0.18
Blackboard	Plywood panelling, 1cm thick	0.22	0.17	0.09	0.10

Simulation 1: Existing acoustic performance

Prior to initiating the simulation procedure, the 3D models for both lecture rooms were generated with the Sketchup Pro® software. Jalil et al. [16], suggest that a reduction in surface areas of approximately 80% is deemed appropriate for the purpose of simplifying the ODEON simulation model. However, the extent of surface reduction exhibited variability due to several factors that could potentially impact the reliability of the findings. These factors include individual modelling approaches, model settings within the simulation software, and the precision of scattering and absorption coefficients associated with the materials. Initially, the number and position of sound source and receivers were pre-determined.

A single point of natural raised sound (BB93_RAISED_NATURAL.SO8) was used as the sound source. The sound source was located 1 m from the front wall and 1.5 m from floor level. As for the receivers, six (6) locations were identified and fixed at 1.2 m from floor level, which represents the student's ear level. The position of the sound source and six (6) receivers were utilised for all classrooms, as depicted in Table 2.

Subsequently, the allocation of surface materials was determined based on the observations made at the location. All surface materials for the 3D models were assigned using the ODEON room acoustic software material library. Table 3 displays the surface materials employed for each individual component of the rooms. The assignment of the scattering coefficient for each surface material is contingent upon the unique features exhibited by the material. Once the setup of the sound source, receivers, and surface materials has been finalised, the model verification process is conducted to ascertain the absence of any geometric errors. The verification was made by analysing water tightness using the 3D investigate ray function. Before the simulation work began, the impulse response length and the number of late rays were determined using the quick estimate function in ODEON. For STI calculation, noise criteria (NC) must be determined beforehand in the ODEON room setup. This study employed the recommended classroom NC of NC-35 for STI evaluation.

The simulation works were classified into three sections, namely: i) simulation of the existing classroom acoustic conditions; ii) simulation of the effect of different ceiling profile configurations on acoustic performance; and iii) simulation of the impact of surface material treatment alternatives on acoustic performance.

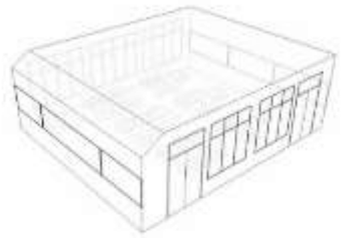
Simulation 2: Ceiling Profile Configuration

This study centres on the effect of various ceiling profiles on classroom acoustic performance, particularly on RT and STI. Four (4) types of ceiling profiles were proposed for the simulation process, namely: i) a single-slope ceiling (30°) above the sound source; ii) a single-slope ceiling (30°) on both sides of the classroom; iii) a single-slope ceiling (30°) above the sound source and on both sides of the classroom; and iv) a reduction of the ceiling height to 2.75 meters. Only the School C classroom 3D design was used for the ceiling profile simulation. The classroom settings, which include surface materials, sound sources, and receivers' locations, remain unchanged. The 3D model details for each proposed ceiling profile are shown in Figure 1.

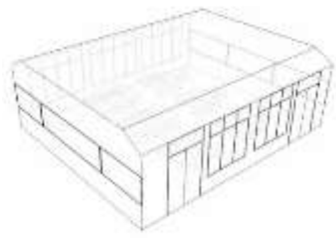
Simulation 3: Surface Materials Treatment

The impact of surface material treatment on RT and STI was further evaluated by utilising the 3D model of the ceiling profile configuration with the best acoustic outcomes. Two (2) surface material treatment alternatives were proposed for the simulation procedures. The details of the surface material treatment alternatives are illustrated in Table 4 and Figure 1.

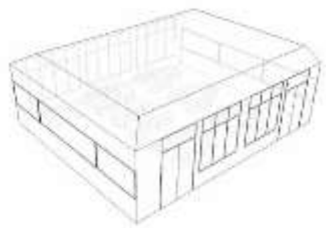
MO: Original ceiling



MO1: Single Slope ceiling (30°) above sound source



MO2: Single Slope ceiling (30°) on both sides of classroom



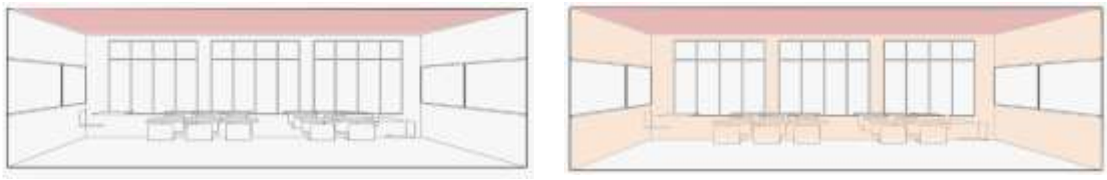
MO3: Single Slope ceiling (30°) above sound source and on both sides of classroom

MO4: Reduction of ceiling height to 2.75 meters

Figure 1: Types of ceiling profiles for acoustic performance simulation

Table 4: Surface materials treatment alternatives details

Treatment alternative	**Surface Component**	**Material**	**Absorption coefficient (α) / Hz**			
			250	**500**	**1000**	**2000**
MO5	Ceiling	Plasterboard on frame, 13mm boards, 100mm empty cavity (Fasold & Winkler, 1976)	0.11	0.05	0.03	0.02
MO6	Ceiling	Plasterboard on frame, 13mm boards, 100mm empty cavity (Fasold & Winkler, 1976)	0.11	0.05	0.03	0.02
	Wall	Panel, 13mm thick, 70mm wide with 2mm slots, on 30mm studs with mineral wool (Stroem, 1979)	0.67	0.49	0.21	0.09

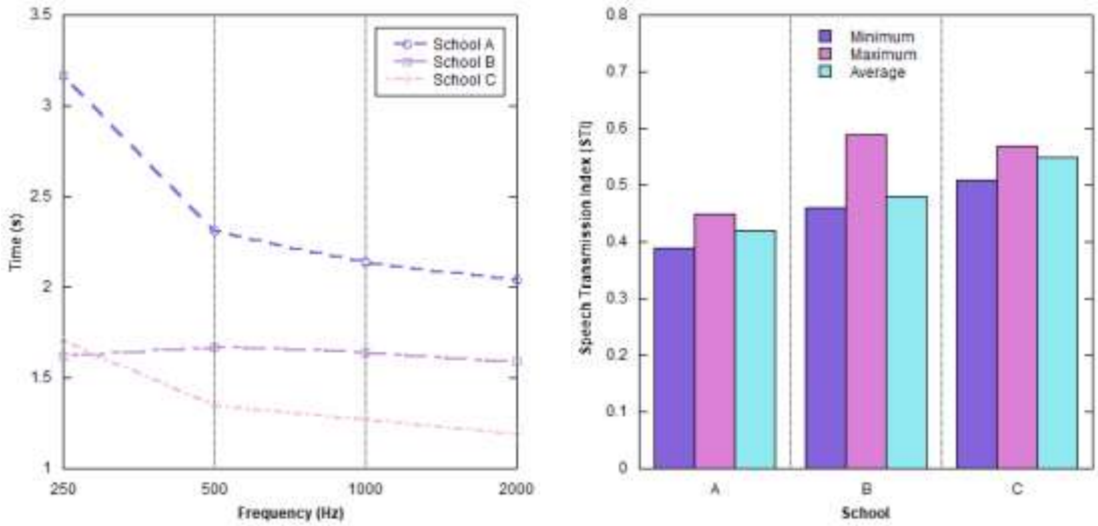


(a) (b)

Figure 1: Interior perspectives of surface treatment alternatives for (a) MO5 and (b) MO6

RESULTS AND FINDINGS

Simulation 1: Reverberation Time (RT) and Speech Transmission Index (STI)



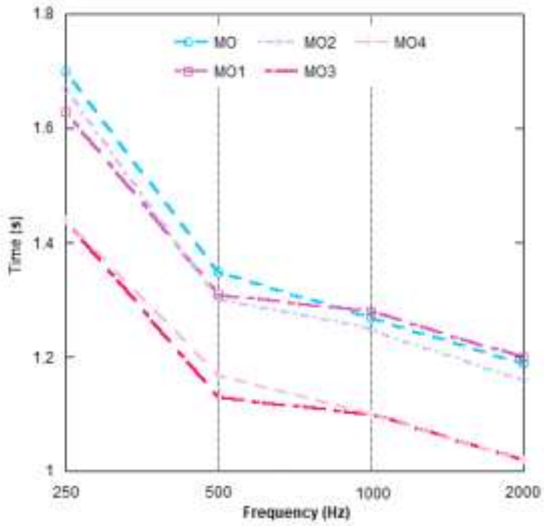
(a) (b)

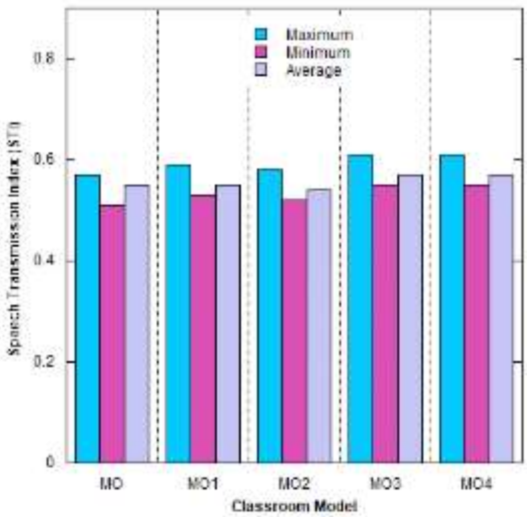
Figure 2: Existing acoustic performance of (a) reverberation time and (b) speech transmission index in public schools

The initial stage of the simulation procedure was conducted in order to examine the prevailing acoustic characteristics of three public schools that were established over distinct time periods. The findings of the RT and STI are depicted in Figures 1a and 1b, respectively. School A demonstrates the highest mean response time (RT) value of 2.42 s, whilst School B and School C exhibit lower RT values with averages of 1.63 s and 1.38 s, respectively. The RT values of all schools did not meet the maximum suggested values of 0.8 s and 1 s, as specified by Building Bulletin 93 and ANSI/ASA S12.60 2010. The variation in RT values observed among public schools can be attributed to the influence of varying ceiling heights, which consequently leads to differences in classroom volumes. Lim et al. [17], reported that a classroom characterised by a considerable ceiling height exhibited unfavourable reverberation conditions. Nevertheless, by decreasing the height of the ceiling, it was possible to see an enhancement in the reverberation duration within the space. Gramez and Boubenider [18] reported that the primary factor contributing to increased reverberation time in a classroom is the utilisation of inappropriate finishing materials for the floor and walls, as well as an excessive presence of reflective materials and consequently, has an impact on learning attainment [18].

Figure 1b illustrates the minimum, maximum, and average results of the STI for all public schools. The analysis revealed that School C exhibits the highest STI value, with an average of 0.55. School A had the lowest STI value, with an average STI rating of 0.42, whereas School B had an average STI rating of 0.48. The STI values observed for the public schools were classified as 'fair' according to the STI grading system. However, these values did not meet the minimal threshold of 0.6, which is considered a good rating. Nevertheless, there is evidence of an improvement in STI ratings as the RT value of public-school classrooms degraded.

Simulation 2: Reverberation time (RT) and Speech Transmission Index (STI)





(a) (b)

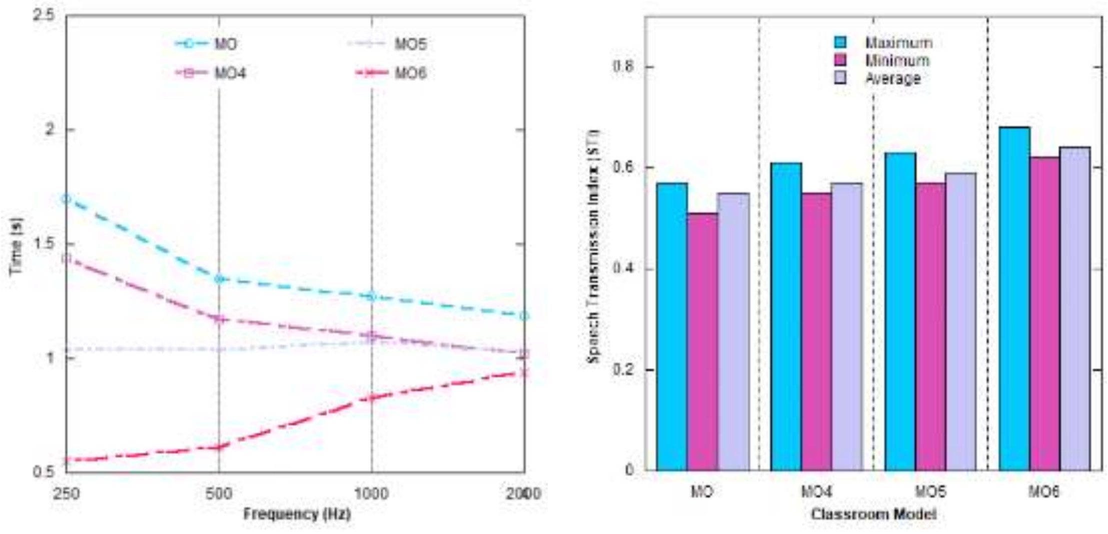
Figure 3: (a) Reverberation time and (b) speech transmission index results of different ceiling profile configurations

The selection of School C's 3D model for simulating various ceiling profiles as an acoustic treatment alternative is based on its relatively low RT value compared to other public schools. The initial state of the classroom in School C was denoted as Model O (MO), while the various options for the ceiling design were classified as MO1-MO4. Referring to Figure 3a, a significant RT improvement was observed in M3 and M4, with an average value of 1.17 s and 1.18 s, respectively. The RT value decreased from 1.38 s to 1.17 s, with an average improvement of 15%. The reduction of the RT value is influenced by the ceiling height profile, which was reduced from 3.15 m to 2.75 m. The results recorded validated the previous findings in regard to the impact of ceiling heights and volumes on room RT conditions.

The STI of various ceiling profiles exhibited comparable outcome patterns. Figure 1b shows the minimum, maximum, and average STI values of MO1-MO4. It was observed that the average STI value increased from 0.55 to 0.57 for MO3 and MO4 ceiling profiles. The early reflection of sound signals improved the STI condition as the ceiling height was lowered down and near the receivers. However, the STI rating has yet to achieve the recommended STI value of 0.6 due to the unfavourable RT conditions.

Simulation 3: Reverberation time (RT) and Speech Transmission Index (STI)
The investigation into enhancing classroom acoustics was extended through an analysis of the effects of surface material treatments on RT and STI. According to the findings from Simulation 2, the classroom models of MO3 and MO4 demonstrated the most favourable outcomes in terms of both RT and STI. Hence, the selection of MO4 for the assessment of surface treatment in Simulation 3 was based on the simplicity nature of the ceiling profile setup. The simulation results of RT and STI based on various surface material treatment possibilities are illustrated in Figures 4a and 4b. The results of MO6 indicate a noteworthy enhancement in both RT and STI, with an average RT value of 0.73 s and a STI rating of 0.64.

The notable result can be attributed to the utilisation of absorptive materials across expansive ceiling and wall regions. The results of MO5 indicate a moderate increase in both RT and STI, with average values of 1.04 s and 0.59 STI-rating, respectively. It is important to note, however, that the observed improvement in MO5 is limited due to the fact that the surface material treatment was applied solely to the ceiling surface, without addressing other building components. The findings obtained indicate that the RT value for MO6 fell within the desired range of 0.8 – 1 s. Additionally, the speech transmission index (STI) rating achieved compliance with the minimum recommended value of 0.6, indicating a good rating. According to Abdullah et al. [19], it has been discovered that the utilisation of appropriate absorptive materials to mitigate reverberation time (RT) results in an enhancement of the Speech Transmission Index (STI) rating in educational environments.



(a) (b)

Figure 4: Surface material treatments results of (a) reverberation time and (b) speech transmission index

CONCLUSIONS

This study extensively conducted simulations to evaluate the acoustic performance of three public secondary schools. The current circumstances of reverberation time (RT) and speech transmission index (STI) in classrooms throughout all schools exceed the maximum permissible range value of 0.8 – 1 s, as specified in Building Bulletin 93 and ANSI/ASA S12.60 2010. There are two distinct treatment methods that have been identified as effective in enhancing the acoustic conditions of classrooms in schools.

These methods include the arrangement of the ceiling profile and the change of the surface material. The findings indicate that altering the ceiling height to 2.75 m and concurrently decreasing the volume of the classroom have a substantial impact on the acoustic characteristics of the classrooms. Subsequent treatment, encompassing the change of surface materials, ultimately resulted in the augmentation of both the room RT and STI values to meet the requirements set by international standards. Hence, the enhancement of optimal classroom acoustic performance can be achieved in ideal circumstances by the implementation of suitable treatment strategies, thereby facilitating a diverse range of teaching and learning methodologies.

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